Magnetically Enhanced Hydrogen Gas Dissociator: A Progress Report

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Application of a sensitive hydrogen gas detector has led to the observation of a significant increase in the efficiency of atom production of a magnetically enhanced dissociator. An increase of about 7000% in the production of atoms in the hyperfine state desired for maser operation is observed at certain values of the applied magnetic field. A preliminary test of the dissociator in the maser has led to an observed increase of 6.18 dB in the maser power.

I. Introduction

The development of the magnetically enhanced hydrogen gas dissociator was initiated in response to a need for improving the operational life of the hydrogen maser. An improvement in the efficiency of the dissociator would result in reduced gas consumption, extending the operational life of vacuum pumps. This would reduce the relatively large number of maser failures which result from the breakdown of Vacion pumps, as often encountered in the field.

Previous investigations involving the application of an axial dc magnetic field on the rf excited dissociator had led to encouraging results (Refs. 1 and 2). The results of these investigations were based on the determination of the flux of the atomic hydrogen effusing from the dissociator with and without the applied magnetic field. These measurements, however, could only yield relative values for the atomic flux; the absolute value of the hydrogen atom flux could not be obtained because of the nature of the measuring technique (Ref. 2).

In the present work we report on our observation of the atomic hydrogen flux as measured directly with a hydrogen atom detector. The use of this detector permitted a further investigation of the dependency of the atomic flux on the strength of the dc magnetic field. The latter results, together with the details of the hydrogen atom detector are subjects of this article.

Section II of this article presents the details of the hydrogen atom detector and Section III provides the result of investigations using the detector. The study will be summarized in Section IV followed by recommendations for future investigations.

II. The Hydrogen Atom Detector

An efficient detection of atomic hydrogen may be accomplished through measurement of the heat released when two hydrogen atoms combine to form a molecule. The amount of heat produced in the reaction $H + H \rightarrow H_2$ is large enough (4.38 eV/reaction) for detection via the measurement of change of resistance of a suitable wire. It can be shown that for a length $2a$ of wire immersed in hydrogen the change in the resistance ΔR is given by:

$$\Delta R = \frac{(R\alpha n\gamma EaD)}{(\pi kd)}$$

Here α is the temperature coefficient of the wire, k is the thermal conductivity, n is the number of atoms per unit area per unit time, γ is the probability of recombination for H on the particular material of the wire, $2E$ is the heat of recombination, d is the diameter of the wire, and D is the atomic beam diameter.

In our studies the expected flux of atoms out of the dissociator is of the order of 10^{15} atoms per second. The atom detector therefore had to be designed with a sensitivity high enough to measure such a flux accurately and efficiently. The apparatus, designed with the above constraint, consisted of two short segments of a thin (2.5 μm in diameter) platinum wire arranged in an ordinary dc bridge circuit (see Fig. 1). The platinum wire was prepared by etching the surface of a Wollaston wire with nitric acid to expose the thin platinum core.

Only one of the segments was exposed to the hydrogen beam, so the difference in the voltage across this segment and that across the second segment could be amplified with a differential amplifier. In this way the detector was sensitive to a hydrogen flux as small as 10^{11}. The detector and its electronic elements were carefully shielded from the rf power used to excite the dissociator. This eliminated a relatively large noise problem which was initially encountered with the detector.

Since the probability of the recombination of H on platinum changes with surface contamination, provisions were made in the detector to periodically clean the surface of the wire through passage of a relatively large (2 mA) current. Thus the sensitivity of the detector was kept at a constant value throughout each run.

The platinum wire detector was placed in a stainless steel vacuum chamber, evacuated with a Vacion pump. The detector was placed on a plate attached to a rotatable feedthrough which could be used to move the plate and the detector in the horizontal direction. The rf excited source was placed external to the vacuum on a flange so that the holes in its exit collimator defined a vertical beam of atoms aligned to intersect the platinum wire. The source, rf exciter, and solenoid providing the dc field are identical to those described previously (Ref. 2).

III. Results and Measurements

As a first test of the hydrogen atom detector we attempted to replicate the previously reported results obtained with the magnetically enhanced dissociator. Under the normal conditions of source pressure and rf power the application of the dc magnetic field resulted in an increase in the source efficiency which agreed closely to the values reported in Refs. 1 and 2.

The increased efficiency of the atom production with the magnetically enhanced dissociator was large enough (up to 70% for certain values of pressure and source power) that an optimization of the beam optics for application in the maser seemed appropriate. We therefore modified the dissociator test apparatus to support a state selecting hexapole magnet at the exit end of the source. This magnet selects atoms of hydrogen that are in the hyperfine ground state having $F = 1$ and $m_F = 1$ and 0 and focuses them on the entrance hole of the storage bulb in the maser. The remainder of the atoms in the $F = 0$ state are defocused and therefore do not enter the storage bulb. This selection is necessary because all atoms that are not in the $F = 1, m_f = 1$ state do not participate in the maser oscillation, and yet they contribute to line broadening through spin exchange collisions.

The observed atom production efficiency of the magnetically enhanced dissociator with the state selecting hexapole magnet in line was quite unexpected. There appeared to be a very significant increase in the production of atoms focused by the state selector. While the flux of atoms which are focused by the hexapole magnet is typically of the order of 10^{13} atoms per second, the application of the dc magnetic field on the source increased the flux of focused atoms by as much as 7000% for a particular value of the applied field. Beyond this, a plot of atomic flux vs. magnetic field revealed pronounced structures which in certain cases implied a decrease to zero for the flux of focused atoms. This result is presented in Fig. 1.

As indicated in Fig. 2, there are a number of features in the plot of flux vs. field. There are two broader peaks at about 150 and 500 Gauss, and a rather sharp peak at about 230 Gauss. A number of valleys are also present including one at about 30 Gauss, which indicates a decrease in the flux of the atoms to zero value. These results were checked for reproducibility many times and were verified each time. They did however indicate changes in the amplitude of the peaks as parameters of rf power and hydrogen pressure were changed.

In view of the remarkable observation presented in Fig. 2, we tested the measuring apparatus to ensure the reliability of results and absence of artifacts. We also examined possible changes in the focusing properties of the hexapole magnet as a result of the presence of the applied dc field. In all cases we reached the conclusion that the results obtained were not due to any artifacts associated with the technique of measurement or the measuring apparatus.

The observed results then clearly indicate that for certain values of the dc magnetic field the total efficiency of atom production of the source is increased. But more importantly, the results indicate a much larger increase, at certain field values, in the production of those atoms in the desired hyperfine state.

This last contention was tested by retrofitting a maser with the magnetically enhanced dissociator and measuring the maser output power. Because of the physical requirement that the solenoid producing the dc field be outside the vacuum chamber, the dissociator had to be placed external to the vacuum chamber of the maser. This produced an increase in the path length of hydrogen atoms by a factor of nearly two, as compared to the path length of atoms when the dissociator is in its usual configuration inside the vacuum chamber.

The result of this test indicated that the maser oscillation ceased when the dc field was at a value which indicated zero atom production in the test bed (about 30 Gauss). As the field increased the maser power increased and reached a level 6.18 dB above its value without the magnetic field for fields larger than about 120 Gauss. The 6.18 dB increase in the power level, however, remained constant for all field values above 120 Gauss.

While this observation verified that the efficiency of atom production in the desired hyperfine state is significantly increased with the application of a dc field, it failed to establish a clear correlation between the observed peaks of Fig. 1 and the maser power. We believe that a clear understanding of this observation will be possible only when modifications are made to ensure that the path length of the atoms in shortened to be equivalent to the length in a normal maser configuration.

At this point it may be appropriate to discuss the possible causes of the behavior of H-atom flux with applied dc field when the hexapole magnet is placed in the beam path. A possible explanation of the observed result is the preferential pumping of the levels of the ground and excited electronic states of hydrogen by the rf power and the cyclotron radiation of electrons circulating in the applied magnetic field. For example, the peak at 230 Gauss could be attributed to pumping of the $2S, F = 1, m_f = -1$ state, which is forbidden to make a transition to the desired ground state, to the $2P$, $F = 1$, $m_f = 1$ state, which is allowed to make the transition. While we have similar explanations for other features in the spectrum depicted in Fig. 2, we believe that a totally conclusive explanation should await further studies with the source in the modified test chamber.

IV. Summary

In this article we have described some details of a hydrogen atom detector which has enabled a comprehensive investigation of the atom production of the magnetically enhanced dissociator. Our observations have revealed that while a significant increase in the production of atoms is obtained, the magnetically enhanced dissociator can increase at a greater proportion the number of atoms in the desired hyperfine state. This observation was further supported when a large (415%) increase was produced in the power output of the maser, which was operated in a test configuration with the magnetically enhanced dissociator. Finally, a preliminary explanation was put forth to describe the physical processes which can lead to the features observed in the spectrum of atomic flux vs. the magnetic field.

While the above results are to be considered quite preliminary, they do imply rather significant contribution to H-maser technology. As discussed in previous works (Refs. 1 and 2), the use of the axially applied magnetic field with the dissociator can enable maser operation at a significantly reduced hydrogen throughput. This will increase the operational life of the vacuum pumps without degrading the maser power output. The observation of the significant increase of the atoms in the desired hyperfine state further implies that for a fixed output power of maser (and therefore a fixed number of desired atoms in the storage bulb) the magnetically enhanced dissociator can lead to significantly reduced line broadening due to spin exchange collisions. This may be brought about since the applied field can evidently increase the ratio of "desired atoms" to "unwanted atoms" in the storage bulb of the maser cavity. Therefore significantly higher line Q's should be expected with the use of the magnetically enhanced dissociator, when all other parameters are kept fixed.

The encouraging results of this investigation have led us to believe that the above investigations should continue to fully determine the ultimate influence of the enhanced source on the operation of the H-maser. Currently further studies are underway to shorten the optical path of the atoms to the normal length as well as to pursue investigations with the test chamber.

References

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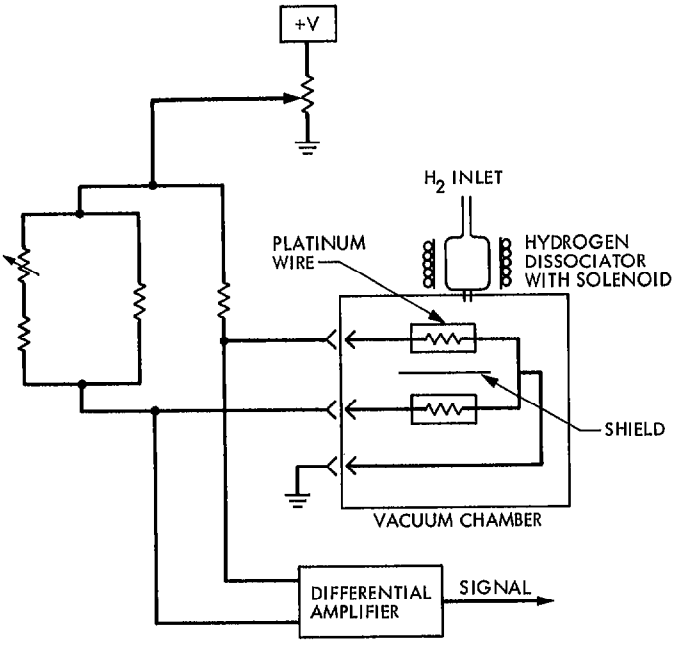

Fig. 1. Block diagram of the hydrogen detector

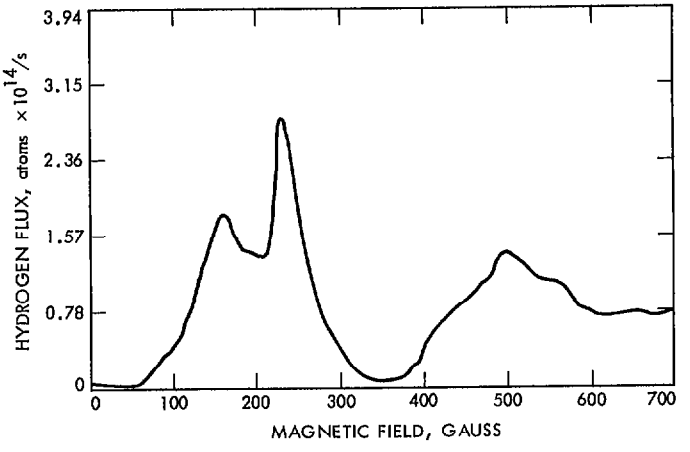

Fig. 2. Plot of flux of hydrogen atoms vs. magnetic field intensity as measured with the atom detector